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## RADIO-- BASIC THEORY AND TECHNIQUE

### Radio, Technical Basics

In order effectively to plan clandestine radio networks, the case officer must have a "speaking acquaintance" with the subject of radio. It is not the intention of this paper to make the reader in any way an expert on the subject, but merely to introduce it.

What is radio? "Radio is a means of transmitting intelligence between two points at the speed of light (186,000 miles per second)." In order to understand how this is accomplished, one must first consider the subject of transmission of energy. Water waves, sound waves and radio waves appear to be widely different phenomena, but they all have certain characteristics in common.

Each type of wave provides the means for transferring energy. It is probable that nearly all energy is transmitted by means of wave motion. When a large steamer plows through the water and sets up waves that rock the small boat half a mile away, it is easy to see that the energy required to do the rocking was transmitted by means of waves. When speech is heard across a room and a radio station is received a thousand miles away, it is not difficult to believe that the energy was transmitted by waves. However, when a man pushes one end of a steel bar and the other end pushes against an object and moves it, it is not so obvious that the energy has been transmitted by wave motion. But if the vibrating cone of a loudspeaker were alternately pulling and pushing at one end of the steel bar, the wave motion which carried the vibration to the other end of the bar would become quite apparent. In this case, if the alternations were rapid enough, it might be found that when the front end of the bar was pushing forward, the other end might already be pulling backward. This would be caused by the length of time it took for the wave to travel down the bar. The same process occurs as when the man pushes the bar, but the time element is so small that the existence of the wave is not generally recognized in this type of motion.

Figure 1 is a representation of wave motion. Part A might represent a cross section of a water wave at a particular moment. If the wave is moving from left to right, Part B would be a picture of the wave an instant later. It will be seen that the crest of the wave which was in position 1 in Part A has moved over to position 2 in Part B. Part C shows the same wave at a still later instant, at which time the crest has moved to position 3. The rate at which the wave is moving from left to right is called the velocity of the wave. Next, consider the motion of the point a, which might be a cork floating on the water, or a particle of the water itself. At the instant represented by A, particle a is on the crest of the wave. An instant later, the

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crest has moved on and the particle has dropped down, as shown in B. Still later, it occupies the position shown in C. While the motion of the wave has been continuously forward, the motion of the particle (a) has been up and down along a vertical line such as 2. The maximum distance either side of the line fg traversed by the particle is called the amplitude of the wave. This is shown on part A as the length h. The distance between successive crests of the wave is called wave length and is represented by the Greek letter  $\lambda$  (lambda). Of course, this is also the distance between successive troughs or any two corresponding points on successive waves. The number of oscillations per second made by a particle such as a is known as the frequency and is designated by the letter f. If the waves were being generated by moving a board up and down in the water, the frequency would depend upon the number of times per second the board was moved up and down. That is, the frequency depends upon the source. On the other hand, the speed at which the waves travelled outwards would be independent of how rapidly the board moved up and down and would be dependent only on the properties of the medium—in this case upon the properties of the water. If some other medium, such as oil or alcohol, were used, the velocity of the waves would be different. The velocity of propagation depends only upon the medium and is independent of the source of the waves. The frequency with which the particle a moves up and down along the line 2 is also the frequency with which the waves are going past the line, for each time a reaches a top peak in its journey up and down, the crest of the wave is going past.

For a given frequency f and velocity of propagation V, the wave length  $\lambda$  is fixed and given by

$$\lambda = \frac{V}{f}$$

$\lambda$  is usually expressed in meters, V in meters per second, and the frequency f in numbers of cycles per second. This can also be written as

$$V = \lambda f,$$

which means that the velocity with which the wave is moving is equal to the length of the wave times the number of waves per second passing a given point.

The velocity of sound in the air is about 344 meters per second, so that a 344 cycle oscillation would produce a wave 1 meter long. The velocity of electromagnetic waves is 300,000,000 meters per second and it requires an oscillation frequency of 300 megacycles to produce a wave 1 meter long.

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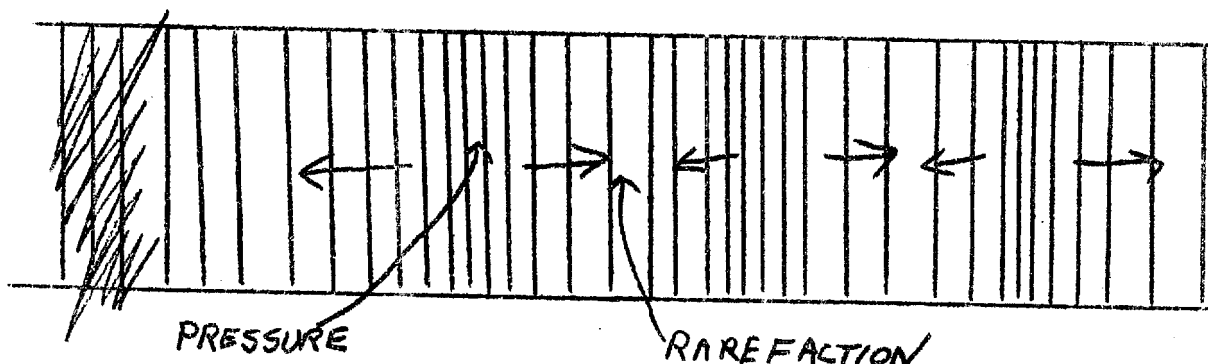


Fig. 2

## LONGITUDINAL WAVE MOTION

The waves pictured in Figure 1 are known as transverse waves because the motion of the particle is at right angles to the direction of the motion of the wave. That is, the wave is moving forward, left to right, and the particle is moving up and down. With the sound waves in the air, on the other hand, the particle motion is back and forth in the direction in which the wave is moving. Such a wave is called a longitudinal wave. It is illustrated in Figure 2 above. The density of the lines represents the pressure in that region. Pressure maxima and minima correspond to the crests and the troughs of the wave in Figure 1. The wave of pressure is moving from left to right and the arrows indicate the direction in which the particles are moving. The particles move in both directions from a pressure maximum to a pressure minimum. The particle movement results in a pressure maximum which is formed where a moment before a pressure minimum existed; in this manner the wave moves on. The individual particles, however, oscillate only back and forth, in a manner similar to the up-and-down oscillation of the particle in the case of the transverse waves.

### Transmission of signals by radio

A communications system is established for the purpose of rapidly transmitting intelligence from one point to another. The two principle means of "instantaneous" transmission are by wire and radio. Radio is the only practical means of communicating with such moving conveyances as boats, airplanes, motor vehicles, etc. When a body of water such as the Atlantic ocean is located between stationary points of communications, radio often proves to be the best system. Radio is also the most logical system to use when the transmissions are to be received at a great many points, as in broadcasting to the general public. The reason for this is

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that the medium for transmission is present everywhere and such a physical connection as a wire between two points is unnecessary.

Radiotelegraphy. The information transmitted may take the form of a message sent in dots and dashes. The method is called radio telegraphy. The transmission is instantaneous.

Radiotelephony. The human voice, music and other sounds may be transmitted by radio. This method is called radiotelephony. The transmission is instantaneous.

Radio communications system. The three principal parts of a communications system are the transmitting station, the medium, and the receiving station. A block diagram of this is shown in Figure 3. The transmitting section is composed of a transmitter which generates and modulates the radio frequency power and an antenna that produces an electromagnetic radiation. The medium conducts the electromagnetic radiation out into space. A receiving station consists essentially of an antenna and a receiver. The receiving antenna is in the electromagnetic field produced by the transmitting station and therefore a current is made to flow through it. The receiver performs the function of converting the current in the receiving antenna into the intelligence that is contained in the transmission.

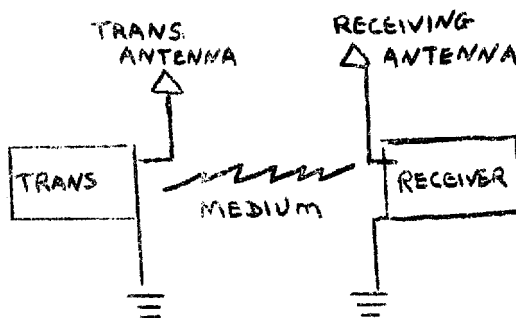
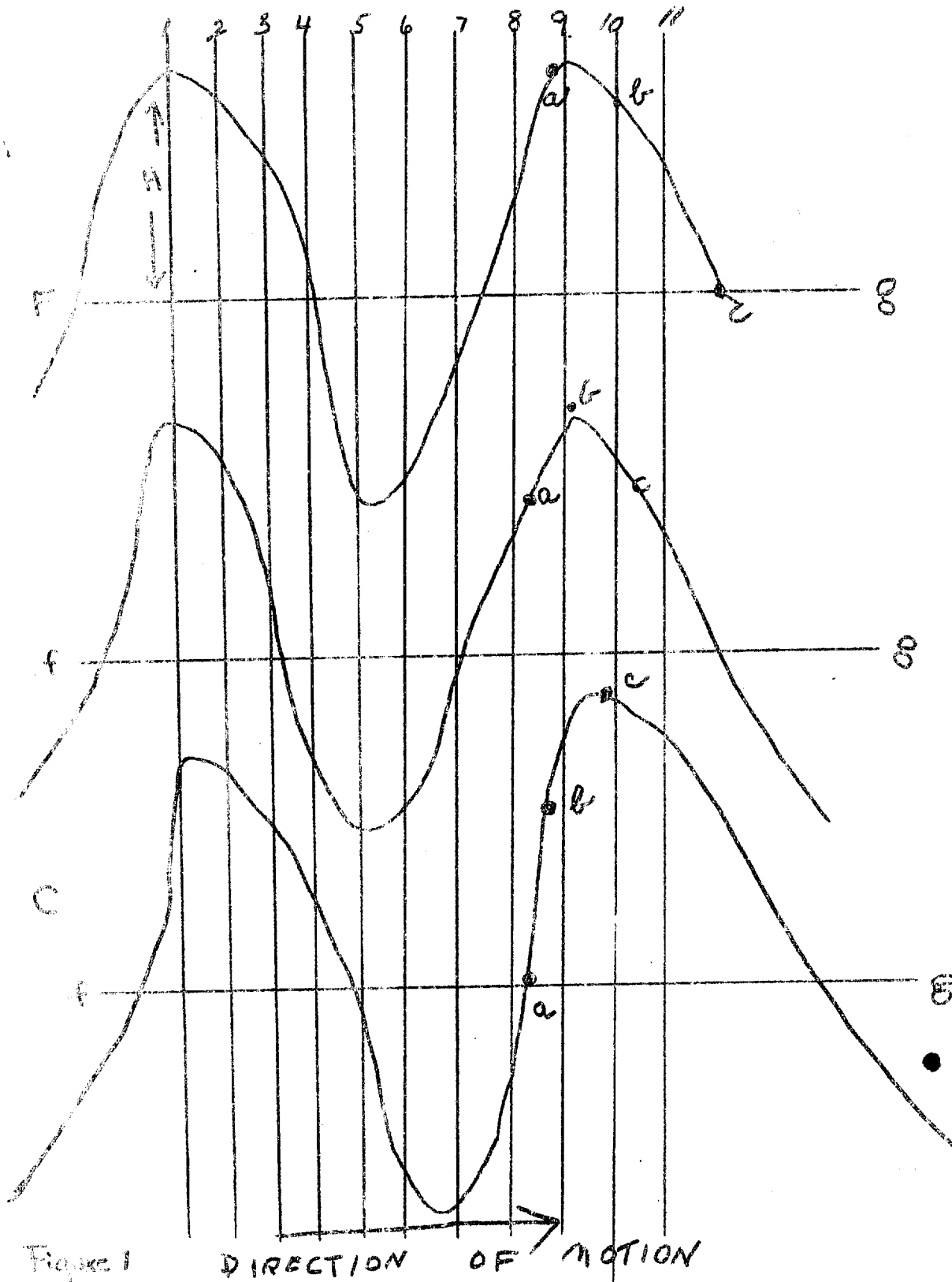


Figure 3

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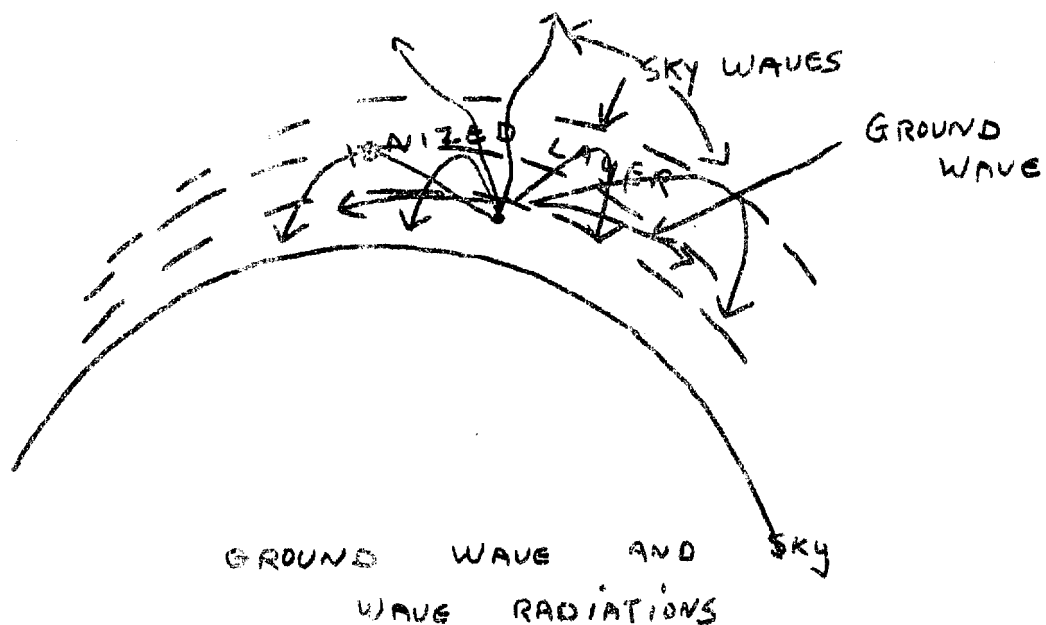
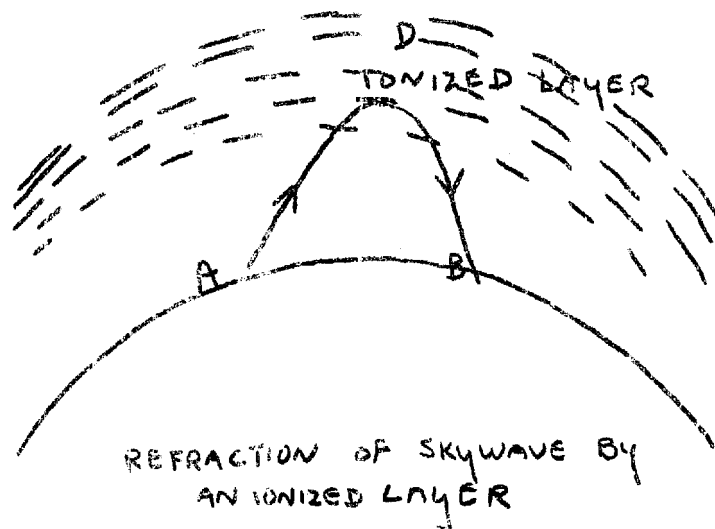


Figure 4

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### General Nature of Propagation

When a radio wave leaves an antenna, it spreads out in all directions, as indicated in Figure 4. Part of the radiated energy travels along the ground and is guided around the surface of the earth, much as electromagnetic waves are guided by wires. This portion of the radiation is called the ground wave, or the surface wave. The remainder of the energy is called the sky wave or the space wave. It is radiated upwards into space and would be lost completely if it were not for the reflecting layers of ions and electrons which exist some 30 to 250 miles above the surface of the earth. These ionized layers can reflect or refract a portion of the incident radiation back toward the earth and so produce a signal at distant points.

The ground wave is the part of the radiated energy which travels along the ground. It induces voltages and currents in the ground which subtract energy from the wave. If the ground were a perfect conductor, these ground currents would flow without any losses and the ground wave would be unaffected. However, since the ground does absorb some of this energy and the strength of the ground wave is reduced as it spreads over an ever-increasing area.

This loss of energy (fading of strength of the ground wave) depends on the absorption (resistance) of the ground and the frequency being used. Over identical ground, a high frequency signal is attenuated much more than a low frequency signal.

Because the ground wave is attenuated so much at the higher frequencies, its chief use lies in the low frequency or broadcast bands. Daytime reception of regular broadcast stations is entirely by means of the ground wave.

The sky wave, or the energy radiated upward by an antenna, would be waste as far as radio communications are concerned, if it continued on its path and did not return to earth. Fortunately, under certain circumstances, it is reflected from the ionosphere, or what used to be called the Kennly-Heaviside Layer. The reflected wave may return to the earth at a distance from the antenna much greater than can be reached by the ground wave. This reflected wave makes extremely long distance communication possible.

The ionosphere consists of several ionized layers--that is, several layers which are electrically conducting. These layers exist in the upper parts of the atmosphere of the earth. Radio waves that strike these conducting layers have their paths changed while passing through the layers. Often the waves penetrate all the layers and are lost, but more often the waves are bent in their paths and return to earth at distant points. The heights of the layers and the degree of ionization determine how far radio waves will go and what frequencies give the best transmission. Sky waves that return to the earth from the ionosphere have been found to come from different heights above the earth, depending on the frequency and the time of reflection.

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There are several layers to the ionosphere which have been generally determined as having an important effect on transmission. These layers may be found at various different heights, depending on time of day and season of the year. Raising or lowering them increases or decreases the angle of reflection, thus bringing the reflected wave back to earth at differing distances for any given frequency. This may have an important effect on agent set operation, in that the distance over which the set may be effective varies according to the time of year and time of day.

It has also been learned that frequency also has a great deal to do with the distance over which a set may be operated. The higher the frequency, the greater the penetration of the ionosphere and the greater the angle of reflection. This angle may eventually approach the point where the reflection no longer returns to the earth and the signal is lost.

The angle of bending may be controlled to a degree by the manner in which the signal is sent out into space. At a given frequency, vertical transmission of the wave might penetrate the ionosphere and be lost while if the same frequency is transmitted at an angle, it may reflect from the ionosphere and return to earth.

This reflection of the radio wave from the ionosphere creates another problem which must be considered in all transmissions: the fact that between the transmitter and the point where the reflected wave strikes the earth, there will exist an area where the signal will not be heard, despite the fact that the intermediate location is considerably nearer to the point of origin than the point where the reflected signal strikes the earth's surface. This blind spot is known as the skip distance. By taking advantage of this phenomenon, it is possible for an agent transmitter to be heard from Germany in Washington, D.C., yet not be picked up in England or San Francisco.

Once the reflected wave strikes the earth, it may be reflected from the earth, since the earth is a partial conductor. This reflected wave may then strike the ionosphere and be reflected once more, striking the earth at a great distance from the transmitter. This type of path is known as two-hop transmission, as compared with the one-hop transmission already mentioned.

Critical Frequencies are the highest frequencies at which waves sent vertically upward are returned by a layer at a particular place and time. The critical frequency for a particular layer is not the highest frequency which can be used for communications using that layer. As has been pointed out, it is necessary only to decrease the angle that the wave path takes in leaving the earth in order to have a higher frequency reflected by the layer.



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Each month the United States Bureau of Standards publishes ionosphere data, including predicted maximum usable frequencies for the ensuing month over any given distance on the basis of one-hop transmission.

Rapid Fading. Gradual fading may occur during changes in ionosphere conditions from season to season and year to year. There are, however, cases in which severe fading occurs rapidly. One of the most startling of the irregular variations in the ionosphere is that known as the radio fadeout. A radio fadeout is the result of a sudden burst of ionizing radiation from the sun which causes the ionization in the E layer (one of the several layers of the ionosphere) to increase suddenly; this in turn greatly increases the absorption of the sky wave at all frequencies. The effect on radio transmission is the sudden fadeout of all signals on frequencies above approximately 1.5 megacycles.

Another and important change in the ionosphere is known as an ionosphere storm. During such a storm, the ionosphere becomes quite unstable in its effects on radio waves, causing signals on about 1.5 megacycles and above to fade and drop in level. A type of fading known as "flutter fading" takes place, especially at night. The effect of these storms is usually the weakening of the sky wave on the broadcast band at night, but sometimes it is increased in strength. Ionosphere storms may last from one to two days on the high frequencies and as long as several weeks on the low frequencies. In the fall of 1948, severe ionospheric disturbances, to all intents and purposes, curtailed high frequency transmissions in the Pacific for three to four weeks.

Ultra-high-frequency propagation. For frequencies above 30 mc, the sky wave is no longer reflected back to the earth from the ionosphere and ground wave transmission is impossible, due to the fact that the earth completely shorts out radio waves at these frequencies. Transmission above 30 mc depends on straight line propagation from the transmitter to the receiver. Because of the curvature of the earth and because the radio waves travel in a straight line from the transmitter to the receiver, the height of the antenna determines how far apart the transmitter and the receiver may be located and still receive the signal.

It is possible, however, that transmission may occur beyond the line of sight, due to the fact that sound waves, radio waves, and light waves may be diffracted or bent around obstacles in their path. The amount of diffraction depends upon the size of the obstacle as compared with the length of the wave. At high frequencies, this bending, although slight as compared with low frequencies, may extend several miles beyond the line of sight.

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Refraction of radio waves occurs due to changes in the density of air in relation to height and changes in temperature, pressure, and the amount of water vapor in the air. This refraction tends to bend the waves back to earth and has an effect in the lower atmosphere similar to the effect of the ionosphere in the upper atmosphere. The increase in the distance in transmission obtained as the result of refraction can be allowed for by considering the earth to be actually flatter than it really is; that is, by assuming its radius to be increased by about 20% to 35%. Signals received by reason of refraction are not as stable as those for direct ray transmission because slight changes in the condition of the atmosphere change the amount of refraction and so produce fading.

Microwave (above 300 mc). In the microwave region, the direct wave must be used and communication is not possible much below the line of sight. Since there is practically no static or fading in this frequency range, reception is very satisfactory. Highly directive antenna arrays can be built in a small space to concentrate the energy in a narrow beam, thus increasing signal strength. Transmission in this region may have some excellent possibilities in shore-to-ship transmission or point-to-point transmission across frontiers and control areas. (See Charts I and II)

Direction Finding (DF'ing) Direction finding, a method with which all field officers should be familiar, is an important consideration in clandestine radio operation. Radio DF'ing usually makes use of directional antennas at the receiver. By using a directional receiving antenna which may be rotated, the direction from which the signal is coming may be determined quite accurately.

If a loop antenna is mounted so that it can be rotated on a vertical axis and tuned to a station, the loudness of the signal received will depend on the direction of the loop with respect to the sending station. If the plane of the loop is at right angles to the line to the station, no signals will be heard, but if it is turned 90° from this position, maximum signals will be heard. Thus, either the position of zero signal (the null position) or the position of the loudest signal could be used for direction finding. The null is usually used, since it gives a sharper indication.

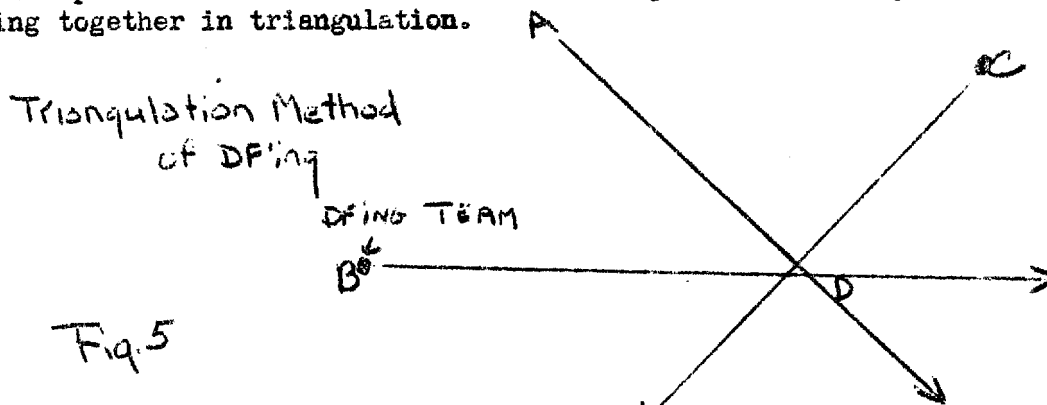
When a loop is turned to either the null position or the position of maximum signal, there is still uncertainty as to whether the signal is coming from the front or the back directions of the loop. This uncertainty exists since there are two positions of the loop for zero signal. The direction may be determined, however, by adding what is known as a sense antenna to the loop arrangement. The sense antenna indicates the direction of the transmitting station. (See Chart III)

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There are, however, other complicating factors in DF'ing. In a neighborhood where there are wires, large metal objects and conductors, errors in the bearing indicators will be noted. Under such conditions, the DF'ing becomes a process of elimination and patience. Of course, an agent radio, operating for short periods on constantly changing frequencies and at different times, complicates further the attempts to locate it by DF'ing.

The troubles from reflected signals, electrical disturbances, etc. are generally associated with DF'ing when the station location is narrowed down to a specific area. The location of the general area of operation is not too difficult for experienced DF'ing teams working together in triangulation.

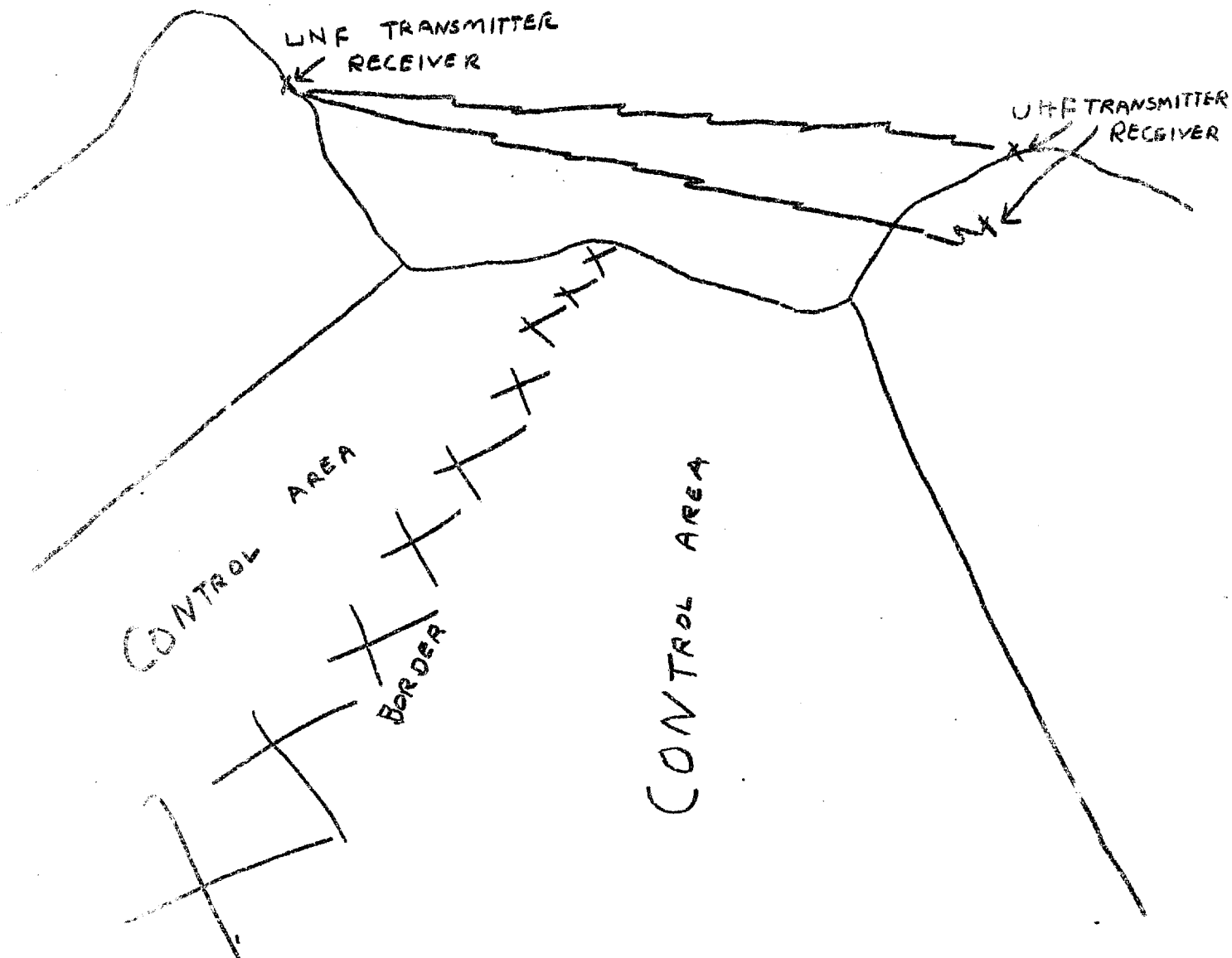


The field officer must never overestimate the capabilities of the equipment with which he deals. The radio transmitter is an instrument of limited means. One of the chief limitations with which the Case Officer is most often concerned is the limitation on power. Power is needed to get signals through--to cover long distances. The agent set is limited in this respect because it is usually a small set which can easily be hidden and which cannot draw power in operation to the point where it will be an unwarranted security hazard. Some agent radios have power outputs as low as 1 watt. Compare this to the thousands of watts of output of some commercial and commercial transmitters.

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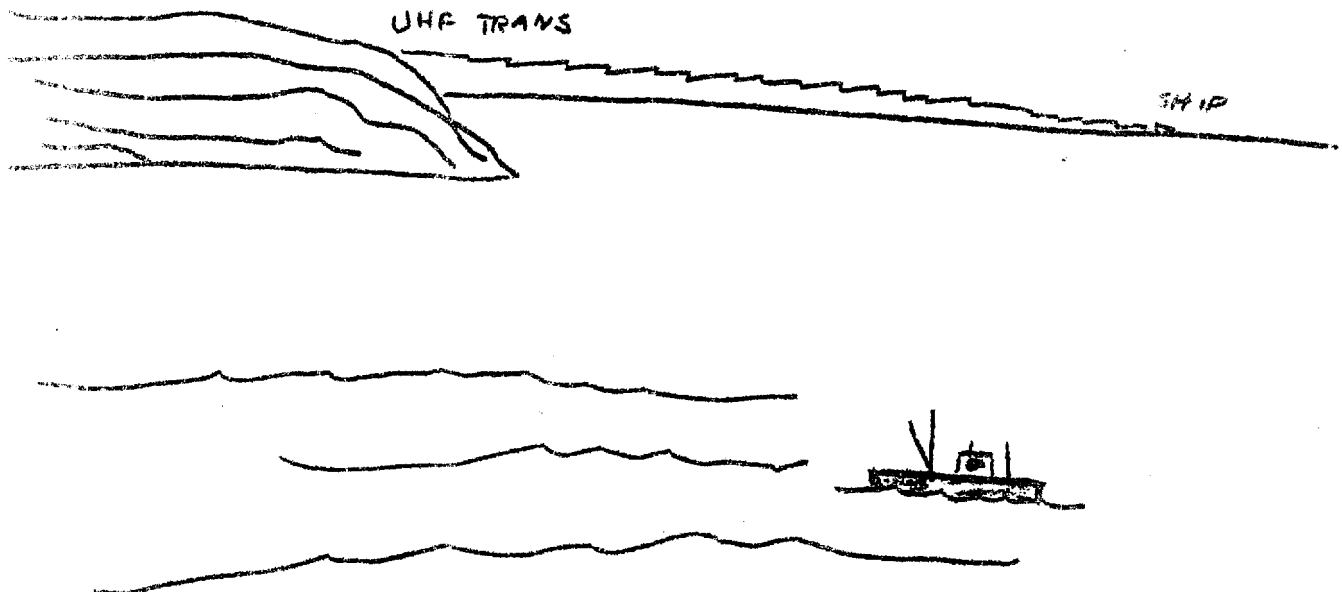
Chart 1. Use of Line-of-Sight Transmission for transmitting Intelligence Across Frontier Barriers



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CHART II. Use of UHF transmitter for shore-to-shore ship radio contact. By use of directional antenna beaming of radio signal, ship in foreground is unable to receive or detect contact between agent transmitter on shore and ship on horizon.



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OUTLINE -- RADIO, BASIC THEORY AND TECHNIQUE

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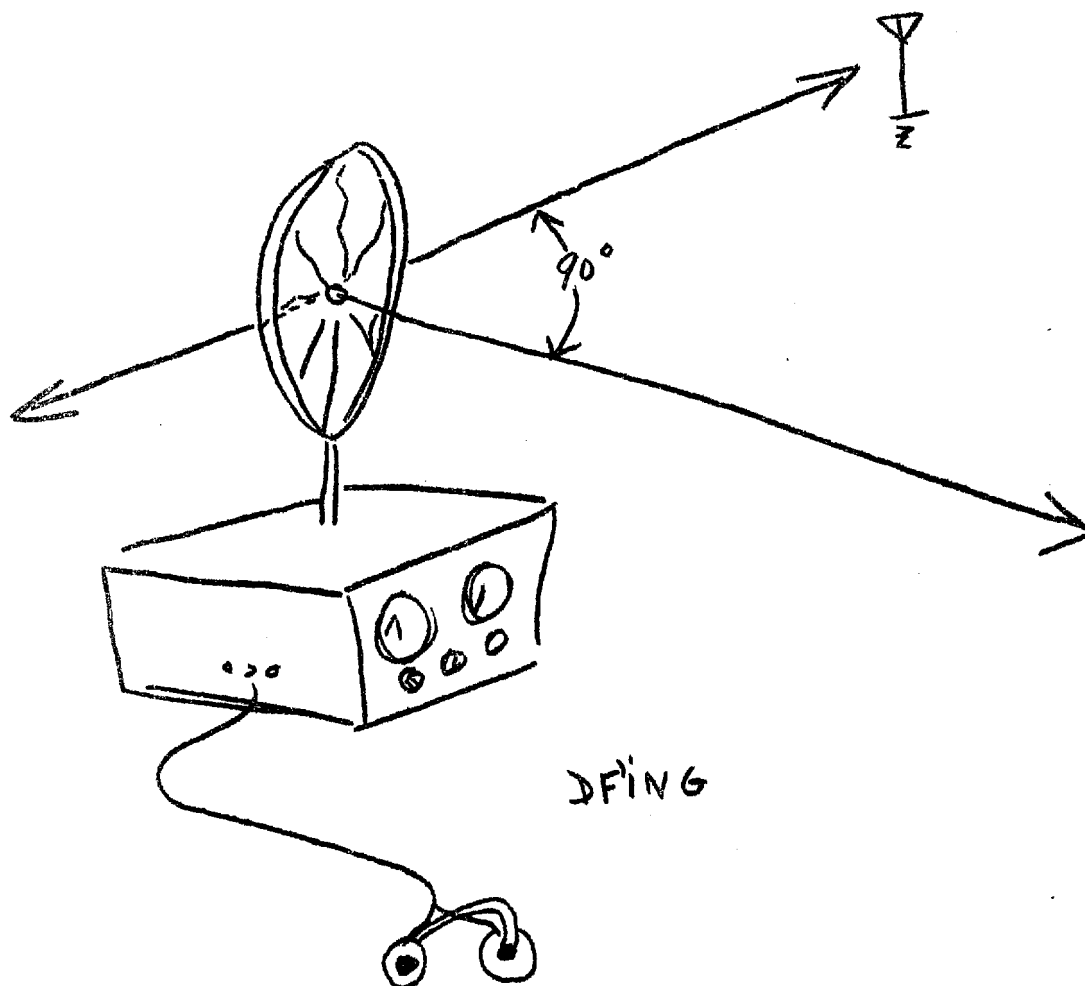


CHART III. NULL Position--parallel to signal source, indication of direction in which transmitter is located.

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**BIBLIOGRAPHY**

Course Operations

SUBJECT RADIO, Basic Theory and Technique

SUBJECT NO. 1-22.20/27 PRESENTED TO Operations Course

SOURCE MATERIAL - References (Basic source desired)

Document No. and Date	Title	Subject matter
Authors: Jordan, Osterbruch, Nelson, Pumphrey, and Smeby Edited by W.L. Everitt, 1942	Fundamentals of Radio	As stated in title
	Elements of Radio	As stated in title
Author: Albert, 1942	Electrical Fundamentals of Communications	
See also: Charts in the Visual Aids Section of TRD		

Signed \_\_\_\_\_

Instructor

Approved:

Date \_\_\_\_\_

Chief Instructor

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